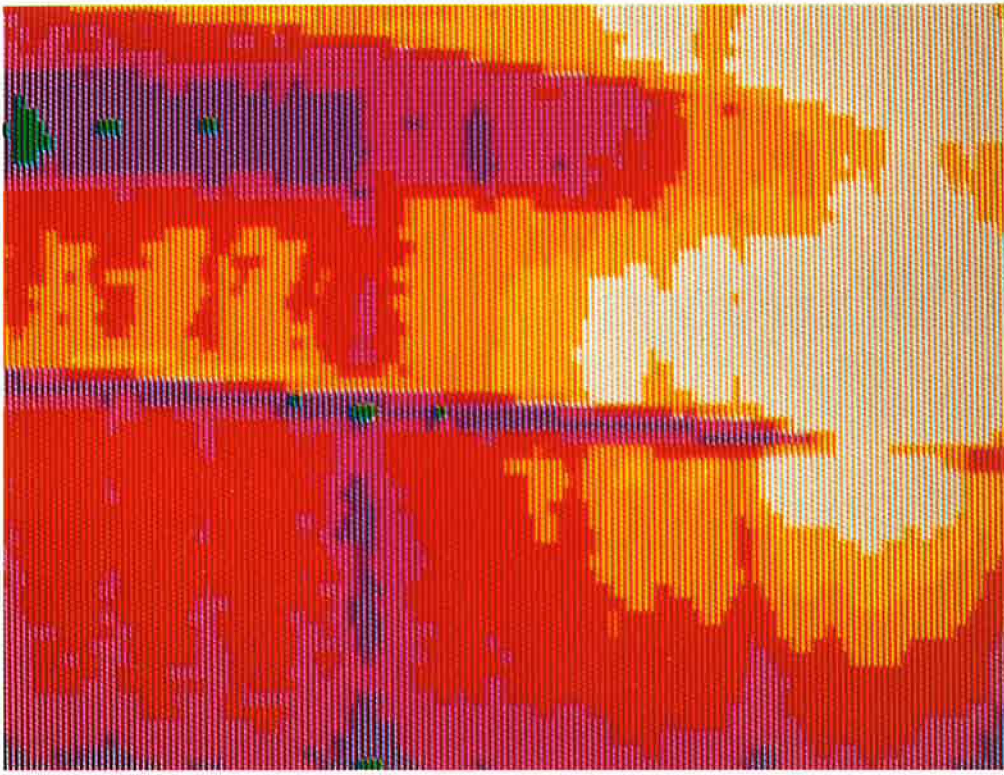
Fuel Efficiency Booklet 16

Economic Thickness of Insulation for Existing Industrial Buildings



Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

BEST PRACTICE PROGRAMME

Economic thickness of insulation for existing industrial buildings

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Cover photograph: Infra-red thermogram of section of inside wall

Contents

1. Introduction

A significant part of energy used in industry (up to half in some engineering industries) is used for space heating. Vast quantities are wasted because of the low priority given in the past to building design in relation to energy conservation. Building Regulations covering thermal insulation now ensure that new buildings, alterations and extensions conform to a minimum standard. It is therefore common sense to bring existing buildings into line with these standards wherever possible.

There are many tried and tested ways of applying structural insulation, both internally and externally, without necessarily interrupting the work of the factory.

This Booklet is aimed at Building Managers and technical staff, and provides a simple method of calculating the economic thickness of insulation added to existing factory buildings for various widely used forms of wall and roof construction. In considering suitable methods of improving the insulation, every effort should be made to identify the materials comprising the existing structure, and the advice of the manufacturers or a consultant should be sought regarding their thermal insulating properties and suitable methods of upgrading.

2. Preventable heat losses

Preventable heat losses are those which can be reduced by the practical and economical insulation of building structure. It may be that there are practical limitations on the thickness of insulation that can be applied, and there will certainly be economic constraints when the return on insulation costs in terms of fuel savings becomes unacceptably low.

As a guide, the following example gives the costs of heat lost and the 'preventable' cost in a fairly typical factory.

This example is based on an uninsulated factory. Many factories fall into this category, whilst many others have a very basic and inadequate level of insulation which also, in many cases, will probably fall well short of an economic standard.

Example

A typical factory in the Midlands has a single skin corrugated roof, with an opaque area of 1,000 m^2. This type of roof has a rate of heat loss of 6.7 W/m^2K (known as its 'U' value). The building is heated by oil over a heating season of 5,500 hours (three shifts working a seven-day week) to attain an internal temperature of 18°C; the average external temperature being 7°C. The boiler is operating at 75% efficiency and the cost of oil is 14 pence per litre (64 pence per gallon).With the existing structure, the cost of heat loss through the opaque part of the roof would be approximately £6,680 per heating season. If insulation is applied to achieve a 'U' value of 0.45 W/m^2K, the cost of heat loss is reduced to £450, a 'preventable' cost of £6,230 per heating season being avoided.

3. Types of insulation

There are many different types of insulation material and systems available, each having quite different thermal performances, handling properties, fire safety and other characteristics.

Details are available from manufacturers or consultants and in technical literature; this booklet can only deal in general terms.

The Tables 4 to 22 in Section 9 list examples of basic construction details, thermal conductivities and thicknesses of materials in common usage, required to achieve a minimum recommended 'U' value of 0.45 W/m^2K or better.

4. Economic thickness of insulation (ETI)

Using a minimum recommended 'U' value of 0.45 W/m^2K is a useful starting point, but it does not take into account individual circumstances. For example, each firm has a different fuel cost and boiler efficiency. These factors, and others, can be brought together by calculating the **Economic Thickness of Insulation**. This shows the thickness which, for a given set of circumstances, results in the lowest overall cost of insulation and heat loss combined over a given

period of time (the evaluation or payback period). Fig 1 demonstrates the principle. It must of course be realised that Fig 1 is merely an idealised representation. In reality insulation costs will be a series of steps, as the insulation is normally supplied in standard thickness. Similarly the heat loss will follow the same pattern as this, too, is dependent on the insulation thickness. It follows that the **Total Cost** must reflect both these types of step change. Certain firms will also affect the calculations by using discounted cash flow (DCF), depreciation costs, future fuel prices and so on. This booklet follows a simple tabulating system to establish the economic thickness; both graphical and numerical methods are shown. Any of the above mentioned variables can be built into the calculations.

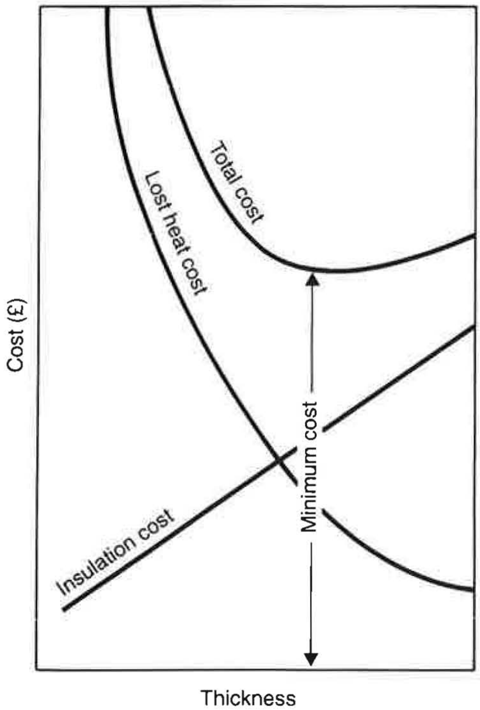


Fig 1 Economic thickness of insulation

5. How to calculate the economic thickness

This simple calculation can be carried out using the nomograms (Method 1) or by the formulae (Method 2) in this booklet. The information necessary for each form of construction is given below:

- the *cost of fuel*;
- the *boiler* or *appliance efficiency*;
- the *total number of hours of operation* of the system per year (see Appendix 2 Glossary);
- the *number of years* over which the investment in insulation is to be paid back by energy savings (evaluation period);
- the *average external winter temperature* (see Fig 4 Average winter temperatures map, Page 10);
- the *average internal temperature*;
- the *existing insulation standard* ('U' value);
- the *proposed insulation standard* ('U' value);
- the *installed cost of the proposed insulation,* in various thicknesses (current installed costs may be obtained from contractors).

6. Step-by-step calculation of economic thickness

The methods described in this booklet are comparatively simple and ignore interest rates, taxation, inflation of fuel prices, etc. Methods are available which take account of these; advice can be obtained from an accountant.

It is best to establish all the information necessary for the calculation before commencing work. A check list of this information is provided in Table 1.

For those not wishing to use the nomograms or tables (perhaps the type of insulation is not tabulated), the calculations can of course be carried out using formulae (see Section 6.2 Method 2). The same nine parameters are required. 'U' values can be obtained from manufacturers or suppliers along with the cost of insulation, or they can be calculated using the formulae given in the Glossary in Appendix 2.

Table 1 Basic information required	
Information	**Units**
Cost of fuel	£ or pence/purchased unit
Boiler or appliance efficiency	%
Annual hours of operation	hours
Evaluation period/pay back period	years
Average external winter temperature	°C
Average internal temperature	°C
Existing insulation standard	W/m^2K
Proposed insulation standards	W/m^2K
Installed cost of proposed insulation standards	£/m^2

6.1 Method 1 - Finding economic thickness using nomograms and tables

The nomograms and the heat loss graph referred to in this section are based on the formulae given in Appendix 1. The following method involves assessing the cost of heat loss plus the cost of insulation at different thicknesses, and then selecting the combination which gives minimum total cost. As some of the scales are logarithmic, they require care in reading. The following steps are illustrated in Fig 2 (Page 4).

Step 1

On Nomogram 1 draw a horizontal line from the appropriate purchase price of fuel to the £/gross GJ column. Read off the gross cost of heat and mark this value on the left hand column of Nomogram 2.

Step 2

Draw a straight line from the assumed boiler or appliance efficiency on Nomogram 2 to the gross cost of heat marked in Step 1, and read off the cost of useful heat. Mark the cost of useful heat on Nomogram 3.

Step 3

For the total hours of operation (see Appendix 2 Glossary), either:

- mark the value on the 'hours' column on the right of Nomogram 3; or
- extend a horizontal line leftwards from one of the 'years' columns to the hours column. and mark the equivalent number of hours.

Draw a straight line from the hours point to the cost of useful heat marked in Step 2. Read off the cost factor and mark it on the left-hand column of Nomogram 4.

Step 4

a Establish 'U' values of the present structure including insulation if any. Then establish the 'U' values with two or three greater thicknesses of insulant to be used from the appropriate Table in Section 9, or from the relevant technical literature. ('U' values can be calculated using the formulae given in the Glossary in Appendix 2.)

b From the Heat Loss Graph (Fig 3) find the heat loss in watts per square metre (W/m^2) for each 'U' value and mark these heat losses on the right-hand column of Nomogram 4.

Step 5

Draw a straight line from each of the heat losses marked in Step 4 to the cost factor already marked in Step 3 and read off total cost of heat loss for each thickness of insulation. Insert the amounts in Table 2.

Step 6

Insert the installed cost of each thickness of insulation in Table 2. (Installed costs should be obtained from a specialist contractor.)

Step 7

Add the cost of the heat lost to the cost of insulation in each case. The lowest of these totals gives the economic thickness.

Table 2 Suggested table layout for recording Step results				
Insulation thickness (mm)	**'U' Value (W/m^2K)**	**Cost of heat lost over evaluation period (£/m^2)**	**Installed cost of insulation (£/m^2)**	**Total Cost (£/m^2)**

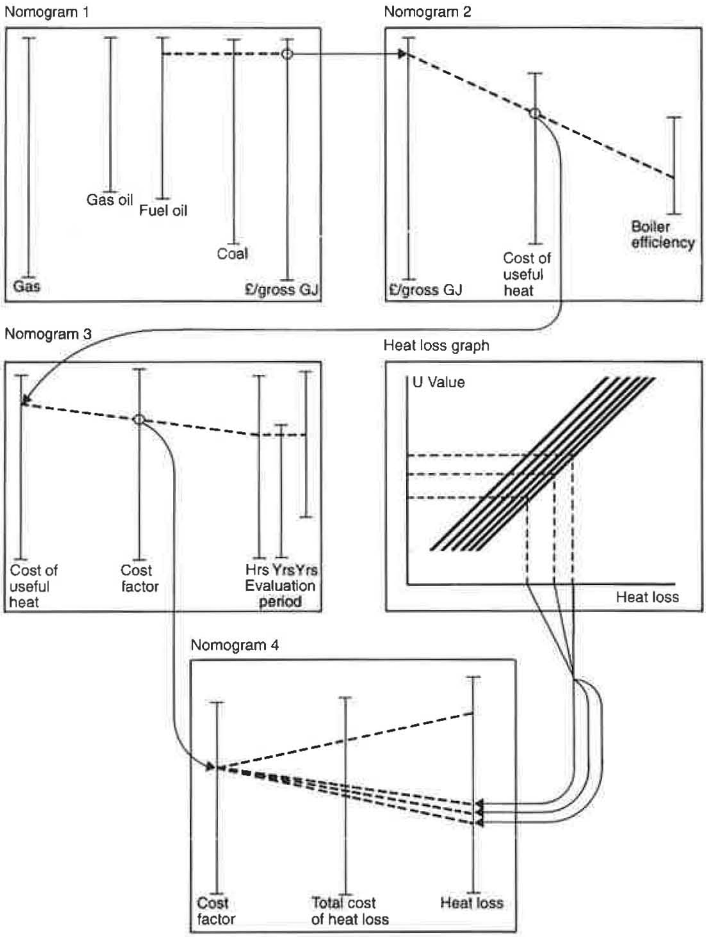
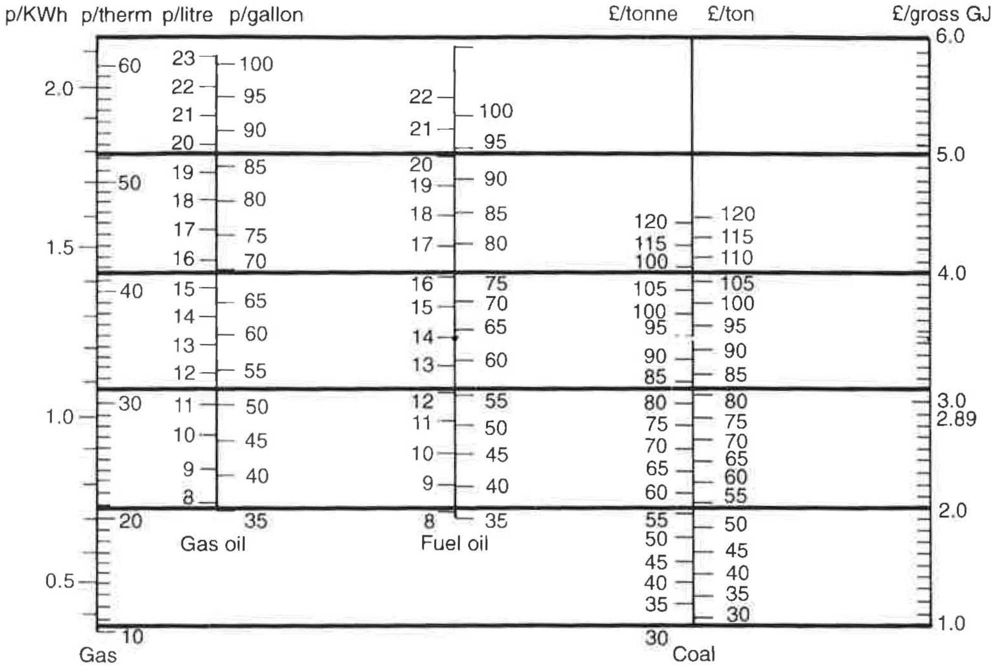
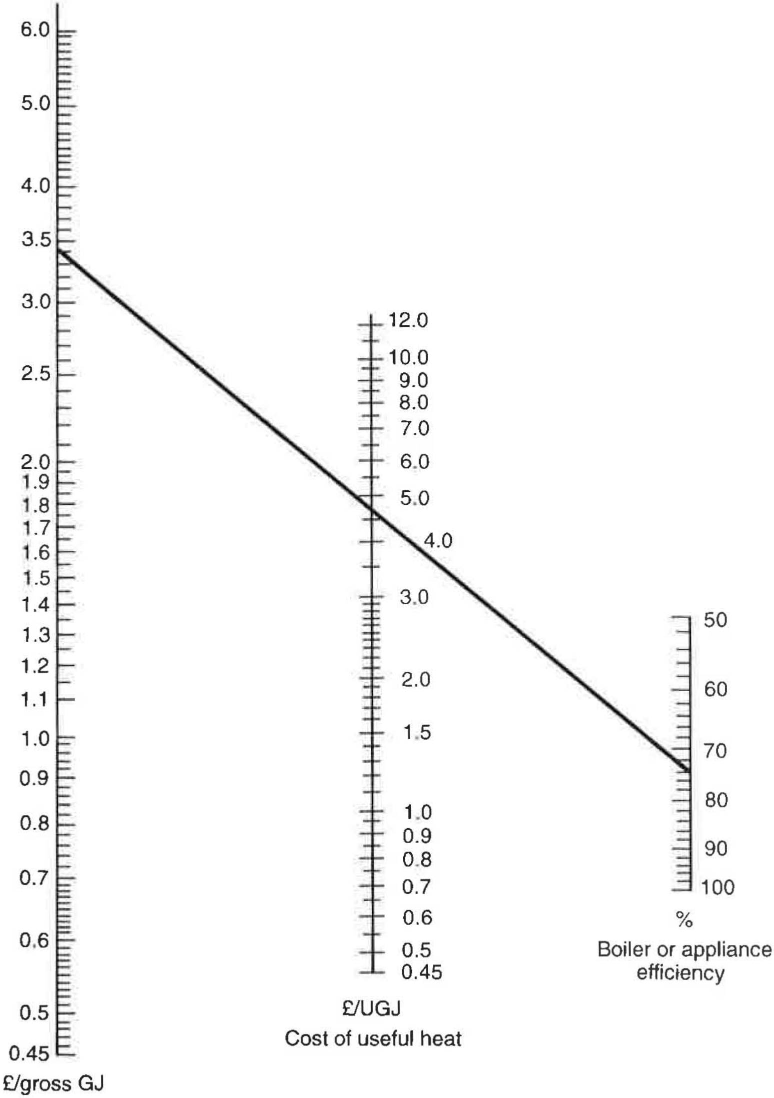


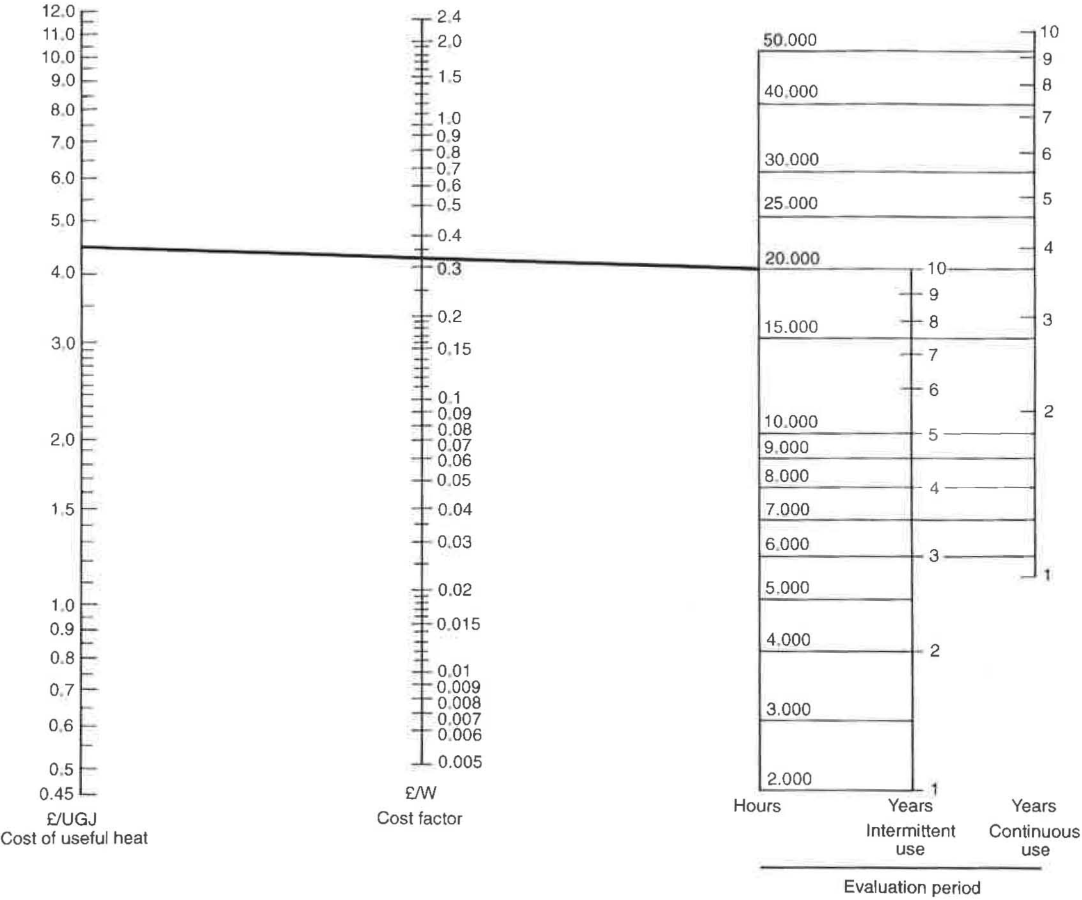
Fig 2 Illustration of Method 1



Nomogram 1 £/Gross GJ



Nomogram 2 Cost of useful heat



Nomogram 3 Cost factor

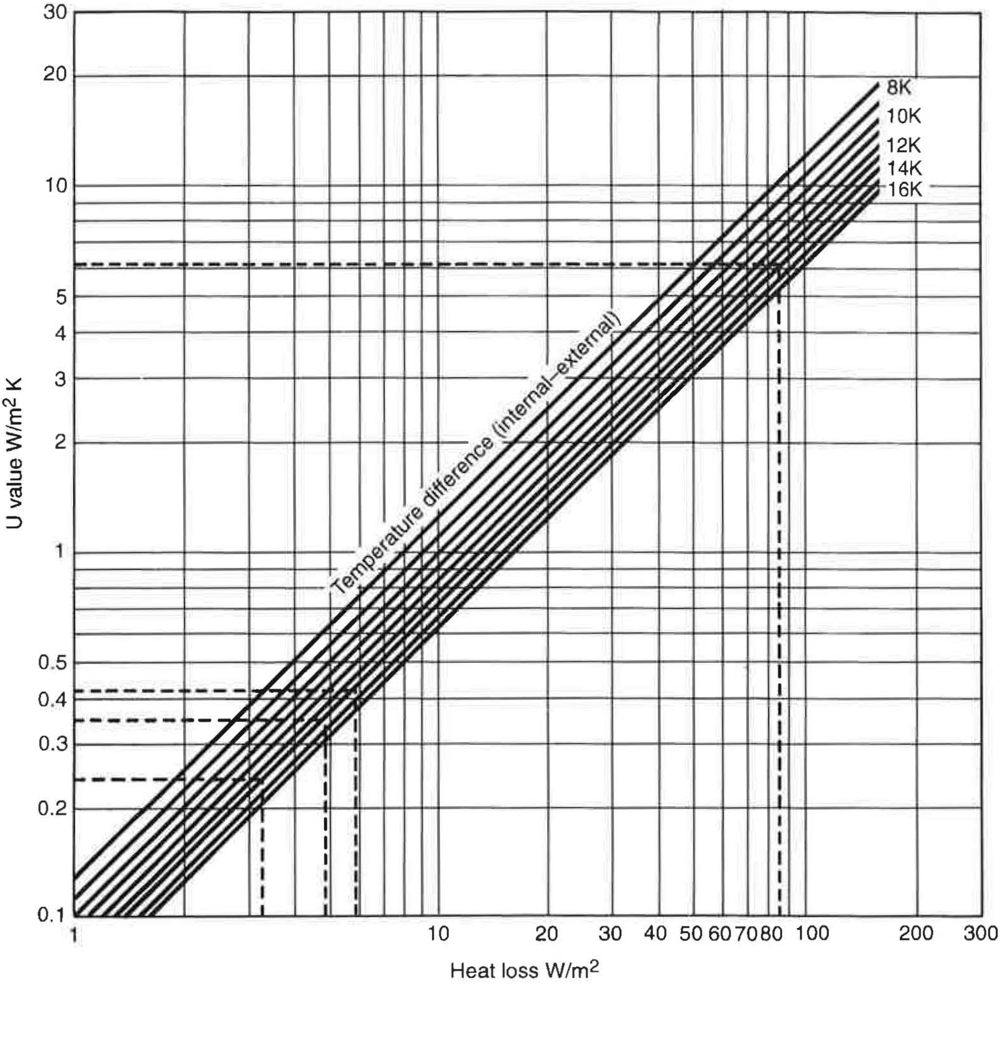
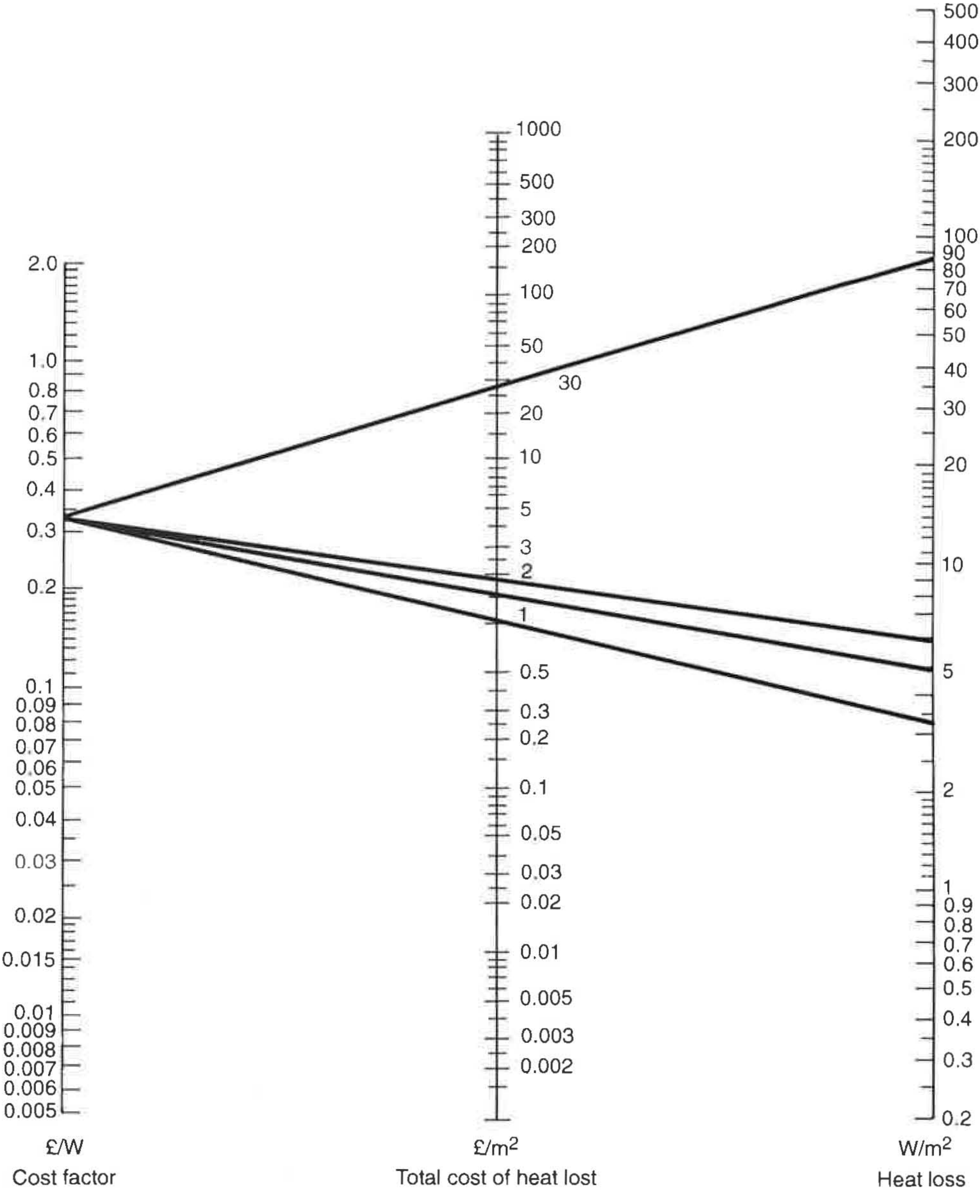


Fig 3 Heat loss graph



Nomogram 4 Total cost of heat lost

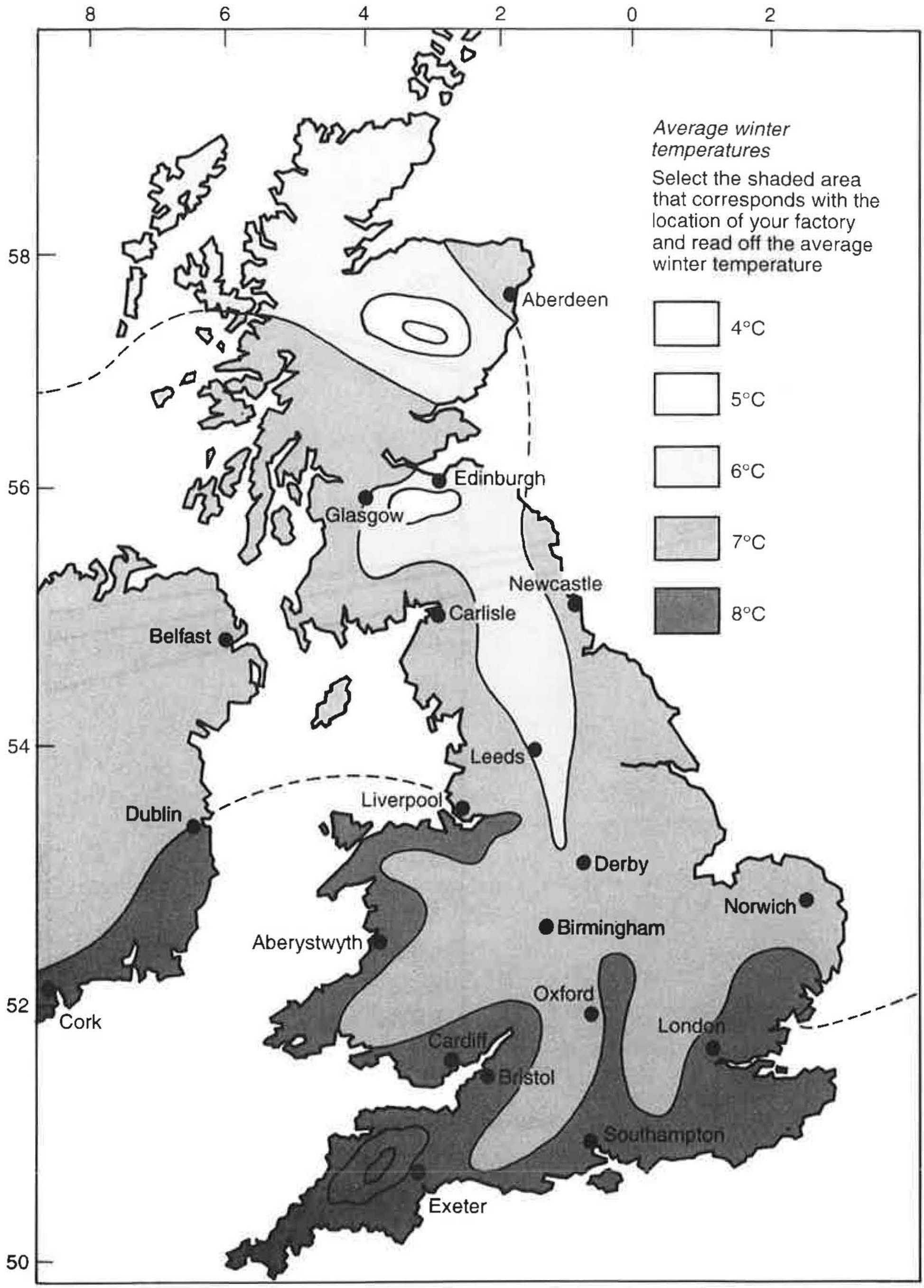


Fig 4 Average winter temperatures

6.1.1 Examples of calculating economic thickness using nomograms and tables (Method 1)

Example 1 (This example is shown on the Nomograms and Fig 3.)

Assume: A factory in Scotland has a single skin non-combustible fibrous cement corrugated roof with an opaque area of 2,000 m^2 and no insulation. Space heating is operated on an intermittent basis, that is single shift, limited overtime, five-day week, giving a heating season of 2,000 hours.

Heating is by an oil-fired boiler which operates at approximately 75% efficiency and the cost of fuel oil is 14 pence per litre (64 pence per gallon). The average internal temperature to be maintained is 19°C and the average external temperature over the heating season is 5°C.

It is proposed that the opaque area of the roof is insulated by underlining with 80 mm, 100 mm or 150 mm rock fibre, supported by 9.5 mm plasterboard, and the investment is to be evaluated over a ten year period using average costs of £9.65, £9.90 and £13.10 per m^2 respectively. What would the economic thickness of insulation be?

Calculations

Step 1

From Nomogram 1 - gross cost of heat = £3.40 per gross GJ

Step 2

From Nomogram 2 - cost of useful heat = £4.60 per useful GJ

Step 3

From Nomogram 3 - cost factor = £0.33/W

Step 4

a From Table 4, Section 9, 'U' values for present structure and with proposed standards of insulation are:

1. 6.10 W/m^2K (uninsulated)
2. 0.42 W/m^2K (80 mm rock fibre with 9.5 mm plasterboard)
3. 0.35 W/m^2K (100 mm rock fibre with 9.5 mm plasterboard)
4. 0.24 W/m^2K (150 mm rock fibre with 9.5 mm plasterboard)

b From the Heat Loss Graph (Fig 3), heat losses (W/m^2) for each 'U' value at a temperature difference of 14K (14°C)[1] are:

1. 85 W/m^2 (uninsulated)
2. 5.9 W/m^2 (80 mm insulation)
3. 4.9 W/m^2 (100 mm insulation)
4. 3.3 W/m^2 (150 mm insulation)

Step 5

From Nomogram 4, for each heat loss determined above at the cost factor of £0.33/W the total costs of heat lost over the evaluation period are:

1. £28/m^2 (uninsulated)
2. £1.90/m^2 (80 mm insulation)
3. £1.60/m^2 (100 mm insulation)
4. £1.10/m^2 (150 mm insulation)

Steps 6 and 7

Produce Table 3, as shown below

Table 3 Insulation of a single skin roof by underlining

Insulation thickness (mm)	'U' Value (W/m^2K)	Cost of heat lost over evaluation period (£/m^2)	Installed cost of insulation (£/m^2)	Total Cost (£/m^2)
0	6.10	28.00	NIL	28.00
80	0.42	1.90	9.65	11.55
100	0.35	1.60	9.90	11.50
150	0.24	1.10	13.10	14.20

The economic thickness of insulation in this instance based on the data shown and on the alternatives considered is therefore 100 mm.

1 Temperature difference is expressed in Kelvin (K). A difference of 1°C is equal to a difference of 1K.

Example 2

A brick-brick cavity wall with lightweight plaster on internal surface is to have cavity fill insulation installed. What is the payback on the applied cost?

'U' values from Table 22, Section 9:

1	1.37 W/m^2K	uninsulated
2	0.56 W/m^2K	with 50 mm blown rock fibre cavity fill

Heating season:	5,500 hours
Temperatures:	Internal 18°C, External 6°C
Efficiency:	75%
Fuel cost:	Gas at 1.396 p/kWh
Insulation cost:	Approximately £2/m^2
Evaluation period:	1 year - for determining annual savings

Calculations

Step 1

From Nomogram 1 - gross cost of heat = £3.90 per gross GJ

Step 2

From Nomogram 2 - cost of useful heat = £5.20 per useful GJ

Step 3

From Nomogram 3 - cost factor = £0.10/W

Step 4

a From Table 22, Section 9, 'U' values for present structure and with proposed insulation are:

1	1.37 W/m^2K	(uninsulated)
2	0.56 W/m^2K	(cavity filled with blown rock fibre)

b From the Heat Loss Graph, Fig 3, heat losses (W/m^2) for each 'U' value at a temperature difference of 12K are:

1	16.4 W/m^2	(uninsulated)
2	6.7 W/m^2	(cavity filled with blown rock fibre)

Step 5

From Nomogram 4, for each heat loss at the cost factor of £0.10/W the total costs of heat lost over the evaluation period of one year are:

1	£1.64/m^2	(uninsulated)
2	£0.67/m^2	(cavity filled with blown rock fibre)

This represents an annual saving of £0.97/m^2 (£1.64/m^2 - £0.67/m^2) resulting in a payback period calculated as follows:

$$\text{Payback period} = \frac{\text{Installed cost of insulation}}{\text{Savings per annum}}$$

$$= \frac{£2/m^2}{£0.97/m^2} = 2.1 \text{ years}$$

6.2 Method 2 - Finding economic thickness using calculations

Instead of using the nomograms, graphs and tables the following calculations can be employed.

The same basic steps must be followed to establish:

- the cost of useful heat
- the cost factor
- the cost of heat lost
- the economic thickness

6.2.1 *The cost of useful heat* (equivalent to *Steps 1 & 2* of Method 1)

The cost of useful heat is based solely upon the cost of fuel and the boiler efficiency. Whilst for the total cost of useful heat many other factors have to be taken into consideration, such as capital costs, maintenance costs, general running costs and so on, these will not change appreciably at the margin. That is to say, they will remain more or less the same even if the heat loss from the building is reduced by using a higher standard of insulation.

It is possible, however, that these costs could be changed if new boiler plant or heating appliances were being considered to meet the existing heating load or new heating loads, necessitated by higher heating standards or extensions to the existing building.

These considerations apart, to find the cost of useful heat it is necessary to take the gross fuel cost (see boxed note) and divide it by the efficiency.

It is therefore necessary to calculate or obtain from the fuel supplier the cost of a gross gigajoule (that is as supplied) and find the cost of a useful gigajoule as previously described.

Some idea of the calorific values of different fuels are listed in Appendix 3 - 'Energy conversion factors'. Values are generally given in megajoules, and to be used in the calculation must be divided by 1,000 to bring them to gigajoules. It is also very important to ensure consistency in the units of fuel quantity (e.g. litres, gallons, tonnes, etc).

Calculating gross fuel cost (£/GJ)

This may cause problems. Although this booklet gives calorific values in the old Imperial units of therms as well as the metric values, it is the metric values that must now be used as **all 'U' values are now in metric units.**

The heat loss is given in terms of watts (W). Whilst most people understand the value of 1 kWh in electrical terms, the relationship between watts and joules (J) may need stating: i.e. 1 watt = 1 joule per second.

In other words, the application of a heat or energy unit of one joule for one second produces the power of one watt.

One watt flowing for one hour (3,600 seconds) therefore supplies 3,600 J. Going further, 1 kilowatt (1,000 watts) flowing for one hour is equivalent to 3,600 J multiplied by 1,000, i.e. 3,600,000 J.

In order to avoid such unwieldy numbers, the SI system employs increments of 1,000. The kilo is well known. Others may not be.

kilo (k)	=	1,000 or 10^3
mega (M)	=	1,000,000 or 10^6
giga (G)	=	1,000,000,000 or 10^9
tera (T)	=	1,000,000,000,000 or 10^{12}

One watt flowing for one hour (kWh) is therefore equivalent to 3,600 J or 3.6 kJ or 0.0036 MJ, and 1 kilowatt flowing for one hour (1 kWh) is equivalent to 3,600,000 J or 3,600 kJ or 3.6 MJ.

The calorific value of fuels can be given in a number of different ways which all adds to possible confusion. Normally in the UK fuel is bought on the basis of Gross Calorific value and this is what is used in this booklet (the Continent tends to use the Net Calorific Value).

Coal can be quoted in Btu per lb, therms per ton or megajoules per tonne.

Fuel oils can be quoted in Btu per gallon, therms per gallon, kilojoules per litre, kilojoules per kilogramme, megajoules per tonne etc.

Gas can be quoted in therms or units of kWh or 100 MJ.

However quoted, these values must be brought into the SI system, i.e. joules, and in this case, because of the size of the numbers involved, the term gigajoule or GJ is used (10^9 joules).

$$\text{Cost of gross gigajoule (GJ)} = \frac{\text{Cost of fuel}}{\text{Calorific value}}$$

Cost of useful gigajoule (UGJ)=

$$\frac{\text{Cost of gross GJ}}{\text{Percentage efficiency}} \times 100$$

Note: Fuel cost may be expressed in terms of kWh. In this case the conversion factor is:

278 kWh = 1 GJ or 1 kWh = 0.0036 GJ.

> ***Example***
>
> **For coal at £60 per tonne, with a gross calorific value of 27,500 megajoules per tonne or 27.5 GJ per tonne (from Table 23, Appendix 3) and boiler efficiency 75%.**
>
> $$\text{cost of gross gigajoule} = \frac{\text{£60/tonne}}{\text{27.5 GJ/tonne}}$$
>
> $$= \text{£2.18/GJ}$$
>
> and
>
> $$\text{cost of useful gigajoule(UGJ)} = \frac{\text{£2.18/GJ}}{75} \times 100$$
>
> $$= \text{£2.90/UGJ}$$

6.2.2 *The cost factor (£/W)* (equivalent to *Step 3* of Method 1)

The cost factor is the value in pounds sterling of a heat loss of one watt **over the evaluation period**.

The decision regarding an evaluation period is one which individual firms will have to make. There is an argument that the evaluation period should be the life of the insulation. Others look for short (say two- or three-year) payback periods.

Whatever period is selected it must be borne in mind that the heat loss in W/m^2 is basically in terms of seconds. If so many years or hours are to be used as an evaluation period, conversion factors must be used.

The simplest method is to express the period in hours, e.g. a seven-year evaluation period on continuous heating becomes 7 x 5,500 = 38,500 hours (see the Glossary in Appendix 2 which gives 5,500 hours per year for continuous heating).

As there are 3,600 seconds in an hour, this time now becomes 38,500 x 3,600 seconds.

The useful heat is given in Gigajoules (joules x 10^9), and as one watt is equal to one joule per second it is necessary to divide the cost factor by 10^9.

Therefore the equation becomes:

Cost factor (£/W)

$$= \frac{\text{£/UGJ x hours of evaluation x 3,600}}{10^9}$$

$$= \frac{\text{£/UGJ x hours of evaluation x 3.6}}{10^6}$$

> ***Example***
>
> Using the £2.9/UGJ from **6.2.1** and an evaluation period of 7 years on continuous heating (38,500 hours) the cost factor would be:
>
> $$\frac{2.9 \times 38{,}500 \times 3.6}{10^6} = 0.40 \text{ £/W}$$

6.2.3 *The cost of the heat lost* (equivalent to *Steps 4 & 5* in Method 1)

The cost of the heat lost over the evaluation period is simply the product of the cost factor (£/W) and the heat loss from the building component (W/m^2).

It has already been described how the cost factor can be calculated, but it has not been shown how the heat loss can be obtained.

The heat loss is dependent upon two factors: one is the thermal transmittance or 'U' value of the building element, and the other is the temperature difference between either side of the element (inside and outside temperatures).

The 'U' value is a convenient way of enabling evaluation of heat loss, but is not something which is measured itself. It is normally built up from results obtained by measuring the properties of individual homogenous components. Details of how the 'U' value is derived are given in Appendix 2.

The 'U' value is expressed in terms of W/m^2K and is a measure of the rate at which heat is lost through a building element. The value given is the number of watts lost for each square metre of element and for each 1 Kelvin difference in temperature from one side to the other.

The rate of heat loss (W/m^2) is defined as:

Temperature difference (K) x 'U' value (W/m^2K)

and the total cost of heat lost (£/m^2) as:

Rate of heat loss (W/m^2) x Cost factor (£/W) (from Section 6.2.2)

Example

Using 100 mm rock fibre mat supported by 9.5 mm industrial grade foil backed plasterboard with a 'U' value of 0.35 W/m^2K (see Section 9, Table 4), and an average internal temperature of 18°C and an average outside temperature of 6°C, the rate of heat loss will be:

$$0.35 \times (18 - 6) = 4.2\ W/m^2.$$

The total cost of heat lost using the cost factor found in Section 6.2.2 is therefore:

$$£0.40/W \times 4.16\ W/m^2 = £1.67/m^2.$$

6.2.4 *Finding the economic thickness*

Steps 6 and 7 can be carried out as described previously for Method 1 in Section 6.1. The economic thickness will again be the insulation thickness corresponding to the lowest value in the Total Cost column.

7. Points to consider

7.1 Ambient conditions

As mentioned previously and in Appendix 2, 'U' values are dependent upon the circumstances in which the insulation is used.

The 'λ' value, or thermal conductivity, of the insulant itself can be seriously affected by the ingress of moisture, either from inside the building due to condensation (see Section 7.5 Practical hints) or from outside due to leakage. The surface resistances can also be affected, but it is principally the outside surface resistance which changes. The influence of exposure and orientation has already been noted and correction factors have been determined to take these into consideration.

7.2 Low night sky temperatures

Solar gain is referred to in Section 8, but low night sky temperature can increase heat losses considerably. Whilst on balance this heat loss may be offset by solar gain so that overall heating requirements are not affected, the maintenance of internal temperature during low night sky temperature periods will certainly mean increased heating. This may mean that larger heating equipment is required. As a guide to take this into consideration, it can be taken that roof temperatures may be 5°C lower than air temperatures at night.

7.3 Evaporative cooling

Another effect, particularly on flat roofs and porous structures (e.g. brick walls) is that of evaporative cooling. This occurs when the structure is wet and moisture is being evaporated as it dries out. Again this effect is intermittent and may be offset by solar gain, but it may lower the surface temperature by some 10°C below ambient.

The effects of low night sky temperatures and evaporative cooling can be offset by insulation as referred to in Section 8.

7.4 Materials and applications

A wide range of insulation products for walls and roofs is available from many different companies. The Heat Loss Graph in Section 6 (Fig 3 (Page 8)) is based on 'U' values which can be achieved with these products. Examples of typical structures, both uninsulated and insulated are given in Section 9.

7.5 Practical hints

When considering upgrading the insulation standards of your building the following factors should be borne in mind.

7.5.1 *Heating controls*

Efficient heating controls are vital to achieving the potential savings. Fuel Efficiency Booklet No 10 - 'Controls and energy savings' - contains useful information about control systems.

7.5.2 *Fire*

Before finalising any specification, check that it conforms to any fire requirements of the Building Regulations, the insurance company and the Local Fire Authority.

7.5 3 *Condensation*

Care must be exercised in any modifications to the structure with regard to condensation, and advice from a consultant or manufacturer should be sought. The safe course is to specify a 'warm' structure, with a vapour barrier incorporated at the warm face of the roof insulation in order to prevent moisture from migrating into the insulant. If an insulant becomes saturated there would be an increased heat loss and a risk of damage. The inclusion of a continuous vapour barrier in an underlining system is not usually a practical proposition and it is therefore essential to ensure that cavities are properly ventilated to the outside atmosphere. In conditions of high humidity, the design will need to be highly specialised and the guidance given in this booklet will not necessarily apply. Further information on condensation can be obtained from sources listed in Section 10.

7.5.4 *Draughts*

Draughts due to defects in the structure itself or due to leaving windows and doors open, will seriously affect the benefits and potential heat savings which can be made by higher standards of insulation. It should be a first priority to ensure that the structure itself is free from holes in walls and roofs and that proper draught sealing is installed. Windows should not be used to ventilate fumes, etc, generated by processes if these can be removed locally by a properly controlled extraction system. Doors should be left open as little as possible, and those which have to be opened and closed frequently or left open for receiving and sending out products, such as those in loading bays, should be examined with a view to fixing flexible doors or air curtains.

7.5.5 *Process air requirements*

It is extremely inefficient to use heated internal air for processes in the building. Air should be fed directly to the plant by ducting from outside the building and draughts around doors, etc. will then be much reduced. Heat can be recovered from industrial processes.

7.5.6 *Incidental gains*

Virtually all factory processes produce some heat which should be allowed for in sizing the heating systems. It is effectively 'free' and the addition of efficient insulation to the building may allow a significant reduction in heating.

7.5.7 *Temperature gradients*

Temperatures at roof level in a building will normally be greater than those at floor level and, if known, the correct figure can be used in the calculations for roofs in this booklet. Temperature gradients will vary with the type of heating system. For example, overhead pipes will give higher temperature gradients than radiant heaters. As a rough guide gradients can be between 0.45 - 0.85°C per metre of building height depending on the type of heating system used. The use of fan systems to force hot air downwards can be an economical solution to high temperatures at roof level. Further information can be obtained from the CIBSE Guide 1986 (see Section 10).

The calculation of savings achievable by insulating a building depends on the distribution of heat being fairly uniform. The figures will not be the same where localised heating is used.

7.5.8 *Structural loading*

Before adding additional loading, the design capabilities of the existing structure should be checked with a consultant engineer.

8. Other benefits of insulation

This booklet is primarily concerned with the economic evaluation of insulation standards, and therefore demonstrates how to assess the savings in annual fuel costs in comparison with the cost of installing better insulation. There are, however, several other benefits which can result from upgrading insulation standards:

- It may be possible to **reduce the size of the heating system** because of lower heat losses. This saving can often offset the cost of improved insulation if both structure and services are being upgraded at the same time.
- The efficient sealing of the walls and roof of a building by the addition of a lining or cladding material will **reduce cold draughts**, improving comfort and further reducing heating costs.
- In summer the **effects of solar heat gain by the roof are reduced**.
- In some cases the **acoustic environment is improved** either by absorption of noise or reduction in sound transmission.

9. Typical structures (Tables 4 to 22)

On the following pages the most common existing structures are described, together with common and proven methods of improving their insulation. 'U' values in the tables are 'rounded' for simplicity and speed of reference.

For specific insulated 'U' values, refer to the appropriate page. Typical structures are quoted and other constructions are given in the Chartered Institution of Building Services Engineers (CIBSE) Guide 1986, Book A, Section A3.

9.1 Introduction to 'U' value tables

Standard densities, thermal conductivities and resistances, as abstracted from Building Research Establishment Digest 108 - 'Standard 'U' Values' - and the CIBSE Guide 1986, Book A, Section A3, have been used throughout for these thermal transmittance ('U' value) calculations.

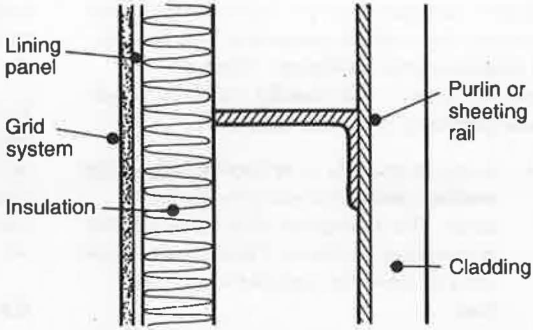
The tabulated specifications shown here do not aim to demonstrate all available systems, but to provide typical examples of constructions commonly encountered and possible insulation modifications.

Table 4 'U' values for lightweight pitched roofs and clad walls

Type of structure

Underpurlin or inside rail lining

		Non-combustible Fibre	Steel
Uninsulated 'U' value (W/m^{2}K)	*Roof*	6.10	6.70
	Wall	5.30	5.70



Type of insulation/construction	**'λ' of insulant (W/mK)**	**Thickness of insulant (mm)**	**'U' value (W/m^{2}K)**	
			roof	**wall**
Rock fibre* mat supported by 9.5mm industrial grade foil backed plasterboard (or similar)	0.040	80 100 150	0.42 0.35 0.24	0.42 0.34 0.23
Rigid glass/rock fibre slab faced with pre-decorated aluminium foil	0.033	75 100	0.39 0.30	0.38 0.29
Polyurethane foam board with white pre-decorated aluminium foil on face, clear coated aluminium foil on reverse side	0.023	40 50	0.45 0.38	0.45 0.37
Industrial grade plasterboard/polyurethane foam board laminate with clear coated aluminium foil backing	0.023	40 plus 9.5mm plasterboard	0.40	0.44
Expanded polystyrene board faced with white pre-decorated aluminium foil or kraft-backed plain aluminium foil	0.034	70 80	0.42 0.37	0.41 0.37
Expanded polystyrene board supported by 9.5mm industrial grade foil backed plasterboard (or similar)	0.037	75 100	0.41 0.32	0.41 0.32

* This term covers both glass and rock fibre.

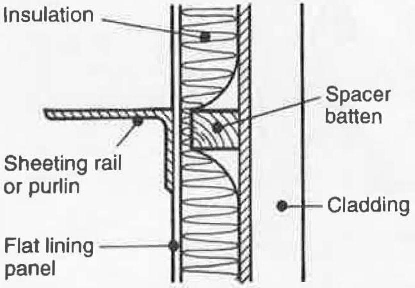
Note: Although these values are calculated using non-combustible fibrous cement sheeting as the base, the differences between this and steel sheeting are small enough to be ignored.

Table 5 'U' values for lightweight pitched roofs and clad walls

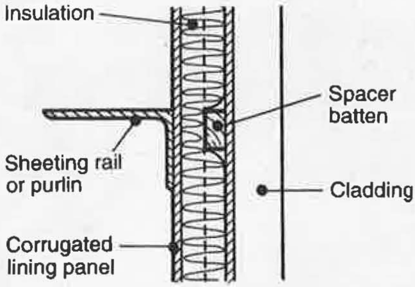
Type of structure

Overpurlin or inside rail lining

		Non-combustible Fibre	Steel
Uninsulated 'U' value (W/m^2K)	*Roof*	6.10	6.70
	Wall	5.30	5.70



(a) replacement of existing cladding with new cladding and lining



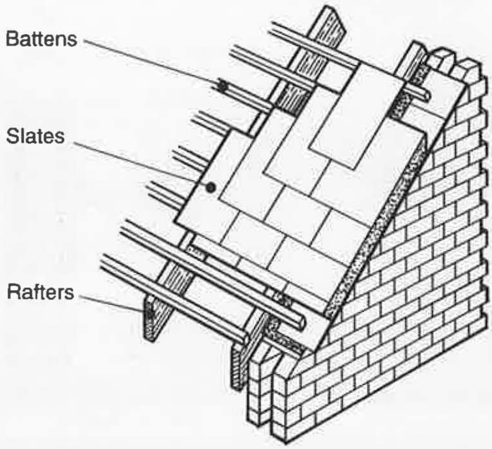
(b) applying insulation and new cladding over existing cladding

Type of insulation/construction	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)	
			roof	wall
Rock fibre* mat supported by 9.5mm industrial grade plasterboard (or similar), incorporating spacers that allow the full thickness of insulation to be effective. Also, mineral fibre mat applied over existing cladding with spacers.	0.040	80 100 150	0.43 0.35 0.24	0.43 0.35 0.24
Rigid glass/rock fibre slab faced with pre-decorated aluminium foil	0.033	75 100	0.40 0.31	0.39 0.30
Polyurethane foam board with white pre-decorated aluminium foil on face, clear coated aluminium foil on reverse side	0.023	50 60	0.40 0.34	0.40 0.34
Industrial grade plasterboard/polyurethane foam board laminate with clear coated aluminium foil backing	0.023	50 plus 9.5mm plasterboard	0.39	0.38
Expanded polystyrene board faced with white pre-decorated aluminium foil	0.034	70 80	0.43 0.38	0.43 0.38
Expanded polystyrene board supported by 9.5mm industrial grade foil backed plasterboard (or similar)	0.037	75 100	0.43 0.33	0.42 0.33
Rock fibre in non-combustible fibrous cement sandwich construction	0.040	90 100	0.44 0.40	0.44 0.39

* This term covers both glass and rock fibre.

Note: Although these values are calculated using non-combustible fibrous cement sheeting as the base, the difference between this and steel sheeting are sufficiently small to be ignored.

Table 6 'U' values for tiled or slated pitched industrial roofs
Type of structure
Slated roof - unfelted — Uninsulated 'U' value (W/m^{2}K) = 6.62



Insulation to be applied following the slope

Type of insulation/construction	**'λ' of insulant (W/mK)**	**Thickness of insulant (mm)**	**'U' value (W/m^{2}K) roof**
Rock fibre* board supported by counter battens with a breather membrane between roof battens and counter battens 9.5mm industrial grade foil backed plasterboard finish (or similar)	0.040	80 100	0.42 0.35
Rigid glass fibre slab faced with pre-decorated aluminium foil	0.033	75	0.39
Polyurethane foam board with white pre-decorated aluminium foil on face, clear coated aluminium foil on reverse side	0.023	40 50	0.46 0.38
Industrial grade plasterboard/polyurethane foam board laminate with clear coated aluminium foil backing	0.023	40 plus 9.5mm plasterboard 50 plus 9.5mm plasterboard	0.45 0.37
Expanded polystyrene board faced with white pre-decorated aluminium foil	0.034	70	0.42
Expanded polystyrene board supported by 9.5mm industrial grade foil backed plasterboard (or similar)	0.037	75 100	0.42 0.33

* This term covers both glass and rock fibre.

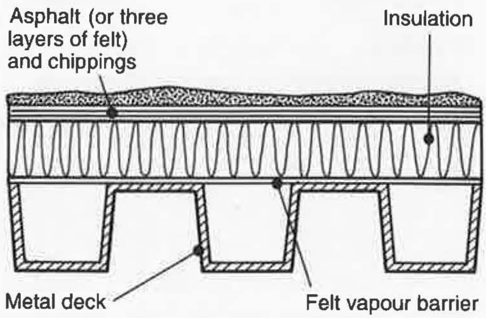
Table 7 'U' values for flat roofs

Type of structure

Metal deck

Uninsulated 'U' value (W/m^2K) = 3.25
(includes 3 layers of felt and 10mm chippings)

With overdeck insulation and weathering



Type of insulation	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
Rigid rock fibre* roof board	0.034	70 100	0.42 0.31
Polyurethane board	0.023	50 60	0.40 0.34
Cellular glass insulating board	0.042	80 90	0.45 0.41
Expanded polystyrene board with 13mm fibreboard overlay (thickness indicated includes fibreboard)	Polystyrene = 0.034 Fibreboard = 0.057	73 83	0.43 0.38

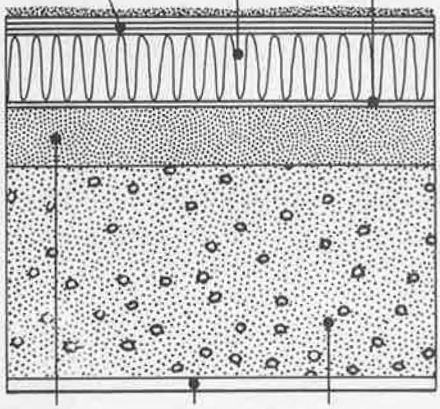
* This term covers both glass and rock fibre.

Table 8 'U' values for flat roofs
Type of structure

Concrete deck

Uninsulated 'U' value (W/m^2K) = 2.60
(includes 3 layers of felt and 10mm chippings)

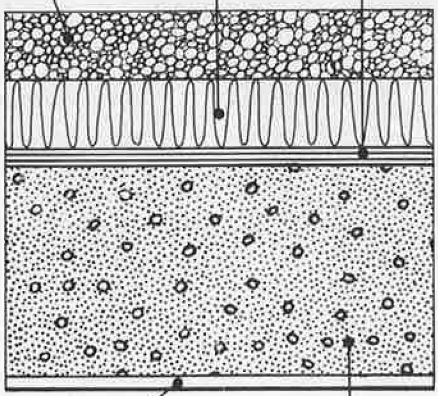
With overdeck insulation and weathering



Type of insulation	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
Rigid rock fibre* roof board	0.034	70 100	0.41 0.30
Polyurethane board	0.023	50	0.39
Cellular glass insulating board	0.042	80 90	0.44 0.4
Expanded polystyrene board with 13mm fibreboard overlay (thickness indicated includes fibreboard)	Polystyrene = 0.034 Fibreboard = 0.057	73 83	0.42 0.37
Lightweight roof insulation screed ($380kg/m^3$ - $560kg/m^3$)	0.070 - 0.096	140	0.42 - 0.50

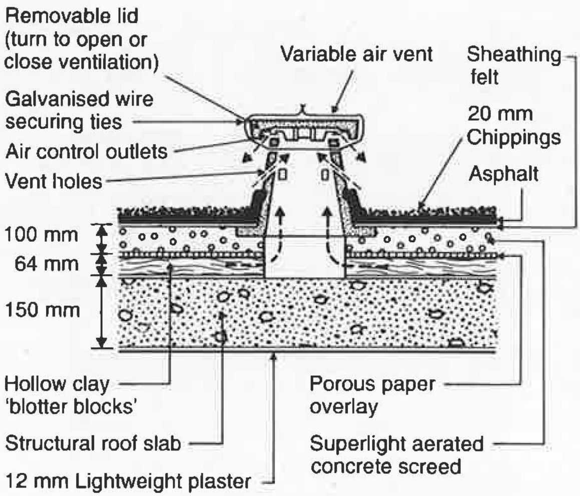
* This term covers both glass and rock fibre.

Table 9 'U' values for flat roofs	
Type of structure	
Concrete deck *'Upside down' roof*	Uninsulated 'U' value (W/m^{2}K) = 2.60 (includes 3 layers of felt and 10mm chippings)



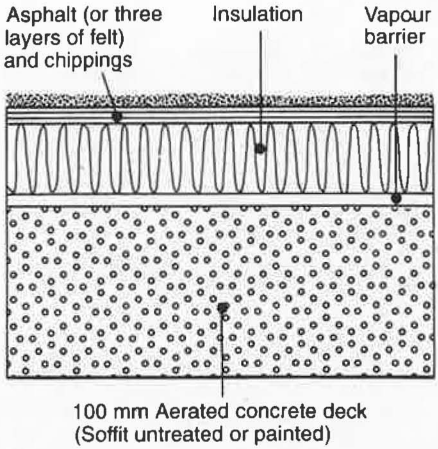
Type of insulation	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^{2}K)
'Upside down' roof. Extruded polystyrene on concrete deck	0.029	50 60 75 80	0.45 0.39 0.32 0.31

Table 10 'U' values for flat roofs	
Type of structure	
Concrete deck – continued *Cavity lightweight roof screed*	Uninsulated 'U' value (W/m^2K) = 2.60 (includes 3 layers of felt and 10mm chippings)



Type of insulation	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
Cavity lightweight concrete roof screed	Light-weight concrete 0.096	Cavity 64 Light-weight screed 160	0.44
		Cavity 64 Light-weight screed 180	0.40

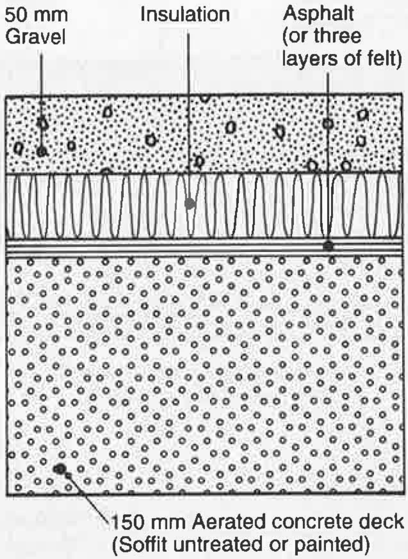
Table 11 'U' values for flat roofs	
Type of structure	
Flat roof – aerated concrete deck *With overdeck insulation and weathering*	Dry density of aerated concrete not exceeding $600 kg/m^3$



Type of insulation	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
Rigid rock fibre* board	0.034	60 80 100	0.4 0.33 0.27
Polyurethane board	0.023	40 60	0.4 0.30
Cellular glass insulating board	0.042	70 90	0.42 0.35
Expanded polystyrene board with 13mm fibreboard overlay (thickness indicated includes fibreboard)	Polystyrene = 0.034 Fibreboard = 0.057	63 73	0.42 0.37
Lightweight roof insulation screed ($380 kg/m^3$ - $560 kg/m^3$) (aerated concrete thickness of 150mm)	0.070 - 0.096	100	0.42 - 0.45

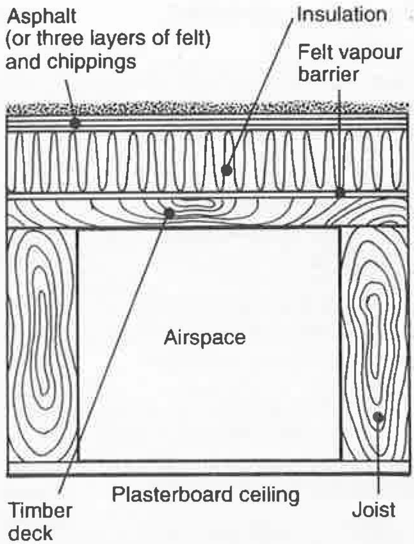
* This term covers both glass and rock fibre.

Table 12 'U' values for flat roofs	
Type of structure	
Flat roof – aerated concrete deck *'Upside down' roof* Dry density of aerated concrete not exceeding 600kg/m^3	Uninsulated 'U' value (W/m2K) = 0.88



Type of insulation	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^{2}K)
Extruded polystyrene on 150mm aerated concrete deck	0.030	40 50 60	0.44 0.37 0.33

Table 13 'U' values for flat roofs	
Type of structure	
Timber deck *With overdeck insulation and weathering*	Uninsulated 'U' value (W/m^2K) = 1.54 (includes 3 layers of felt and 10mm chippings)

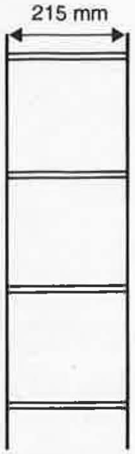


Type of insulation	**'λ' of insulant (W/mK)**	**Thickness of insulant (mm)**	**'U' value (W/m^2K)**
Rigid rock fibre* roof board	0.034	60 70 100	0.41 0.37 0.28
Polyurethane board	0.023	40 50	0.42 0.36
Cellular glass insulating board	0.042	70 80 90	0.43 0.39 0.36
Expanded polystyrene board with 13mm fibreboard overlay (thickness indicated includes fibreboard)	Polystyrene = 0.034 Fibreboard = 0.057	63 73	0.42 0.37

* This term covers both glass and rock fibre.

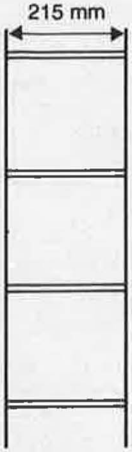
Table 14 'U' values for masonry walls				
Type of structure	**Type of insulation/construction**	**'λ' of insulant (W/mK)**	**Thickness of insulant (mm)**	**'U' value (W/m^2K)**
 Single leaf or solid dense block wall; EXISTING CONSTRUCTION	1. 215mm ($8^1/_2$in) solid brick wall – unplastered and uninsulated	0.084 External leaf brick	215 Brick	2.30
EXISTING CONSTRUCTION	2. 215mm solid brick wall with 13mm dense plaster on internal surface or 19mm render on external surface	0.50 Dense plaster 0.73 External render	13 Dense plaster 19 External render	2.17
EXISTING CONSTRUCTION	3. 215mm solid brick wall with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	1.94
EXISTING CONSTRUCTION	4. 215mm solid brick wall with 9.5mm plasterboard lining on 20mm (min) battens to internal surface	0.16 Plasterboard	29.5 Board and battens	1.5
EXISTING CONSTRUCTION	5. 215mm solid brick wall with 9.5mm foil-backed plasterboard on 20mm (min) battens to internal surface	0.16 Plaster and low emmissivity foil and air cavity	29.5 Board and battens	1.18
CIBSE GUIDE TABLE A3.15 Brick dry density = 1,700kg/m^3; CIBSE GUIDE TABLE A3.1 'λ' Values	6. 215mm solid brick wall with 13mm foil backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	70 Polystyrene + 33 board&battens 80 Polystyrene + 33 board&battens	0.42 0.37
External leaf 0.84 W/mK at 5% v/v moist; Internal leaf 0.62 W/mK at 1% v/v moist	7. 215mm solid brick wall with 9.5mm foil backed plasterboard and 75mm rock fibre* to internal surface. Board to brick facing by 50mm spacer battens	0.04 Rock fibre	84.5 Board and mineral fibre	0.42

* This term covers both glass and rock fibre.

Table 15 'U' values for masonry walls					
Type of structure		**Type of insulation/construction**	**'λ' of insulant (W/mK)**	**Thickness of insulant (mm)**	**'U' value (W/m^2K)**
	EXISTING CONSTRUCTION	1. 215mm (8½in) solid dense block wall, unplastered and uninsulated	1.80	215 Dense block	3.3
		2. 215mm solid dense wall with 13mm dense plaster on internal surface or 19mm render on external surface	0.56 Dense plaster 0.73 External render	13 Dense plaster 19 External render	3.1 3.0
		3. 215mm solid dense wall with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	2.63
		4. 215mm solid dense block wall with 9.5mm plasterboard lining on 20mm (min) battens to internal surface	0.16 Plasterboard	29.5 Board and battens	1.80
Single leaf or solid common brick wall		5. 215mm solid dense block wall with 9.5mm foil-backed plasterboard on 20mm (min) battens to internal surface	0.16 Plaster and low emmissivity foil and air cavity combination	29.5 Board and battens	1.50
CIBSE GUIDE TABLE A3.15 Heavyweight Block dry density = $2,300kg/m^3$		6. 215mm solid dense block wall with 13mm foil backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	70 Polystyrene + 33 board&battens 80 Polystyrene + 33 board&battens	0.44 0.39
CIBSE GUIDE TABLE A3.1 'λ' Values at 3% v/v moist = 1.63W/mK at 5% v/v moist = 1.80W/mK		7. 215mm solid dense block wall with 9.5mm foil backed plasterboard and 75mm rock fibre* to internal surface. Board to brick facing by 75mm spacer battens	0.04 Rock fibre	84.5 Board and mineral fibre	0.45

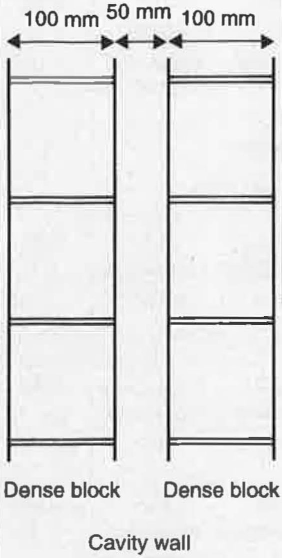
* This term covers both glass and rock fibre.

Table 16 'U' values for masonry walls

Type of structure	Type of insulation/construction	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
 Single leaf or lightweight block wall EXISTING CONSTRUCTION	1. 215mm ($8^1/_2$in) solid lightweight block wall, unplastered and no other insulation	0.2 Lightweight block	215	0.80
	2. 215mm ($8^1/_2$in) solid lightweight block with 13mm dense plaster on internal surface and 19mm render on external surface	0.56 Dense plaster 0.73 External render	13 Dense plaster 19 External render	0.77
	3. Externally rendered 215mm solid lightweight block with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	0.73
	4. Externally rendered 215mm solid lightweight block with 9.5mm plasterboard on 20mm (min) battens to internal surface	0.16 Plasterboard	29.5 Board and battens	0.67
	5. Externally rendered 215mm solid lightweight block with 9.5mm foil-backed plasterboard on 20mm (min) battens to internal surface	0.16 Plaster and low emmissivity foil and air cavity combination	29.5 Board and battens	0.59
	6. Externally rendered 215mm solid lightweight block with 13mm foil-backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	40 Polystyrene + 33 Board & battens	0.41
CIBSE GUIDE TABLE A3.15 Lightweight block dry density = $600kg/m^3$ CIBSE GUIDE TABLE A3.1 'λ' Values at 3% v/v moist = 0.19 W/mK at 5% v/v moist = 0.20 W/mK	7. Externally rendered 215mm solid lightweight block with 9.5mm foil-backed plasterboard and 50mm rock fibre* to internal surface board to brick facing by 50mm spacer battens	0.04 Mineral fibre	59.5 Board and mineral fibre	0.39
	8. Externally rendered 215mm solid lightweight block with 9.5mm foil backed plasterboard and 75mm rock fibre* to internal surface board to brick facing by 75mm spacer battens	0.04 Rock fibre	84.5 Board and mineral fibre	0.31

* This term covers both glass and rock fibre.

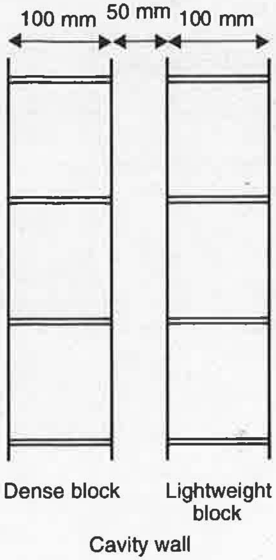
Table 17 'U' values for masonry walls



Type of structure		Type of insulation/construction	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
Cavity wall (see drawing above)	EXISTING CONSTRUCTION	1. 2 x 100mm dense block leaves, 50mm air cavity, unplastered and uninsulated	1.63 Inner leaf 1.80 Outer leaf	250 Block leaves and cavity	2.10
	EXISTING CONSTRUCTION	2. 2 x 100mm dense block leaves, 50mm air cavity, with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	1.79
		3. As 1, with 13mm foil-backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	70 Polystyrene + 33 Board & battens	0.41
		4. As 1, with 9.5mm foil-backed plasterboard and 75mm rock fibre* to internal surface and 75mm spacer battens	0.04 Rock fibre	84.5 Board and mineral fibre	0.42
CIBSE GUIDE TABLE A3.15 Heavyweight block dry density = 2,300kg/m^3 CIBSE GUIDE TABLE A3.1 'λ' Values Outer leaf 1.80 W/mK at 5% v/v moist Inner leaf 1.63 W/mK at 3% v/v moist		5. As 2, with cavity filled with blown rock fibre and 13mm lightweight plaster on internal surface	0.04 Specified cavity fill	13 Lightweight plaster 50 Specified cavity fill	0.61

* This term covers both glass and rock fibre.

Table 18 'U' values for masonry walls



CIBSE GUIDE TABLE A3.15
Lightweight block dry density = 600kg/m^3

Heavyweight block dry density = 2,300kg/m^3

CIBSE GUIDE TABLE A3.1 'λ' Values

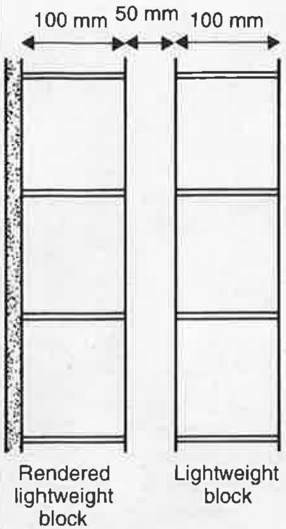
Heavyweight outer leaf 1.80 W/mK at 5% v/v moist

Lightweight inner leaf 0.19 W/mK at 3% v/v moist

Type of structure	Type of insulation/construction	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^{2}K)
EXISTING CONSTRUCTION	1. 2 x 100mm dense outer and lightweight inner block leaves, 50mm air cavity, unplastered and uninsulated	1.80 External dense leaf 0.19 Internal lightweight leaf	250 Block leaves and cavity	1.06
EXISTING CONSTRUCTION	2. 2 x 100mm dense outer and lightweight inner block leaves, 50mm air cavity, with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	0.98
	3. As 1, with 13mm foil-backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	50 Polystyrene + 33 Board & battens	0.42
	4. As 1, with 9.5mm foil-backed plasterboard and 50mm rock fibre* to internal surface and 50mm spacer battens	0.04 Rock fibre	59.5 Board and mineral fibre	0.44
	5. As 1, with 9.5mm foil backed plasterboard and 75mm rock fibre* to internal surface and 75mm spacer battens	0.04 Mineral Fibre	84.5 Board and mineral fibre	0.33
	6. As 2, with cavity filled with blown rock fibre and 13mm lightweight plaster on internal surface	0.04 Specified cavity fill	13 Lightweight plaster 50 Specified cavity fill	0.48

* This term covers both glass and rock fibre.

Table 19 'U' values for masonry walls

<table>
<tr><th>Type of structure</th><th></th><th>Type of insulation/construction</th><th>'λ' of insulant (W/mK)</th><th>Thickness of insulant (mm)</th><th>'U' value (W/m^2K)</th></tr>
<tr><td rowspan="5">

Cavity wall

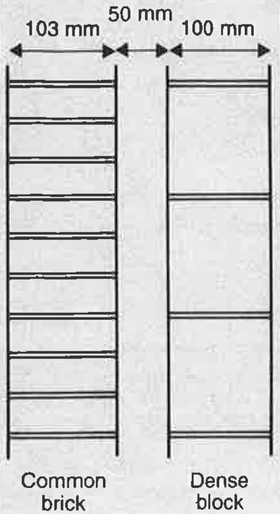
CIBSE GUIDE TABLE A3.15
Lightweight block dry density = 600kg/m^3

CIBSE GUIDE TABLE A3.1 'λ' Values

Outer leaf 0.2 W/mK at 5% v/v moist

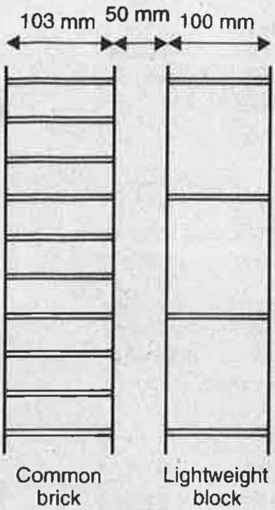
Inner leaf 0.19 W/mK at 3% v/v moist</td><td rowspan="2">EXISTING CONSTRUCTION</td><td>1. 2 x 100mm lightweight block leaves, 19mm external render, 50mm air cavity, unplastered and uninsulated</td><td>0.73 External leaf
0.19 Inner lightweight leaf
0.02 Outer lightweight leaf</td><td>269 Block leaves render and cavity</td><td>0.71</td></tr>
<tr><td>2. 2 x 100mm lightweight block leaves, 19mm external render, 50mm air cavity, with 13mm lightweight plaster on internal surface</td><td>0.16 Lightweight plaster</td><td>13 Lightweight plaster</td><td>0.67</td></tr>
<tr><td></td><td>3. As 1, with 13mm foil-backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface</td><td>0.037 Expanded polystyrene</td><td>30 Polystyrene + 33 Board & battens
40 Polystyrene + 33 Boards & battens</td><td>0.43
0.39</td></tr>
<tr><td></td><td>4. As 1, with 9.5mm foil-backed plasterboard and 50mm rock fibre* to internal surface - 50mm spacer battens</td><td>0.04 Rock fibre</td><td>59.5 Board and mineral fibre</td><td>0.37</td></tr>
<tr><td></td><td>5. As 2, with cavity filled with blown rock fibre and 13mm lightweight plaster on internal surface</td><td>0.04 Specified cavity fill</td><td>13 Lightweight plaster
50 Specified cavity fill</td><td>0.39</td></tr>
</table>

* This term covers both glass and rock fibre.

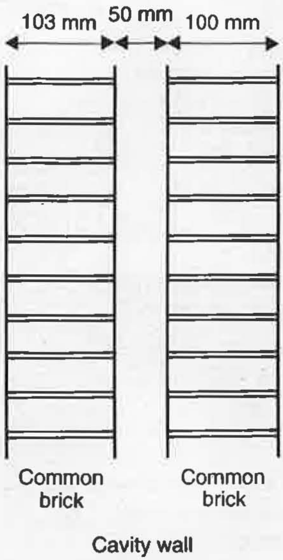
Table 20 'U' values for masonry walls					
Type of structure		**Type of insulation/construction**	**'λ' of insulant (W/mK)**	**Thickness of insulant (mm)**	**'U' value (W/m^2K)**
 Cavity wall	EXISTING CONSTRUCTION	1. 103mm brick outer and 100mm dense block inner leaves, 50mm air cavity unplastered and uninsulated	0.84 External leaf brick 1.63 Internal dense block	253 Brick/Block leaves and cavity	1.84
	EXISTING CONSTRUCTION	2. 103mm brick outer and 100mm dense block inner leaves, 50mm air cavity with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	1.6
		3. As 1, with 13mm foil-backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	60 Polystyrene + 33 Board & battens 70 Polystyrene + 33 Boards & battens	0.44 0.40
CIBSE GUIDE TABLE A3.15 Brick dry density = 1,700kg/m^3 Heavyweight block dry density = 2,300kg/m^3 CIBSE GUIDE TABLE A3.1 'λ' Values Brick outer leaf 0.84 W/mK at 5% v/v moist Heavyweight block inner leaf 1.63 W/mK at 3% v/v moist		4. As 1, with 9.5mm foil-backed plasterboard and 75mm rock fibre* to internal surface and 75mm spacer battens	0.04 Rock fibre	84.5 Board and mineral fibre	0.4
		5. As 2, with cavity filled with blown rock fibre and 13mm lightweight plaster on internal surface	0.04 Specified cavity fill	13 Lightweight plaster 50 Specified cavity fill	0.59

* This term covers both glass and rock fibre.

Table 21 'U' values for masonry walls

Type of structure		Type of insulation/construction	'λ' of insulant (W/mK)	Thickness of insulant (mm)	'U' value (W/m^2K)
 Cavity wall	EXISTING CONSTRUCTION	1. 103mm brick outer and 100mm lightweight block inner leaves, 50mm air cavity unplastered and uninsulated	0.84 External leaf brick 0.19 Internal lightweight block	253 Brick/Block leaves and cavity	0.99
	EXISTING CONSTRUCTION	2. 103mm brick outer and 100mm lightweight block inner leaves, 50mm air cavity with 13mm lightweight plaster on internal surface	0.16 Lightweight plaster	13 Lightweight plaster	0.92
		3. As 1, with 13mm plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface	0.037 Expanded polystyrene	50 Polystyrene + 33 Board & battens	0.41
CIBSE GUIDE TABLE A3.15 Brick dry density = $1,700kg/m^3$		4. As 1, with 9.5mm plasterboard and 50mm rock fibre* to internal surface - 50mm spacer battens	0.04 Rock fibre	59.5 Board and mineral fibre	0.43
Lightweight block dry density = $600kg/m^3$ CIBSE GUIDE TABLE A3.1 'λ' Values Brick outer leaf 0.84 W/mK at 5% v/v moist Lightweight block inner leaf 0.19 W/mK at 3% v/v moist		5. As 2, with cavity filled with blown rock fibre and 13mm lightweight plaster on internal surface	0.04 Specified cavity fill	13 Lightweight plaster 50 Specified cavity fill	0.46

* This term covers both glass and rock fibre.

<table>
<tr><th colspan="6">Table 22 'U' values for masonry walls</th></tr>
<tr><th colspan="2">Type of structure</th><th>Type of insulation/construction</th><th>'λ' of insulant (W/mK)</th><th>Thickness of insulant (mm)</th><th>'U' value (W/m^2K)</th></tr>
<tr><td rowspan="5">

CIBSE GUIDE TABLE A3.15 Brick dry density = $1,700 kg/m^3$
CIBSE GUIDE TABLE A3.1 'λ' Values
Outer leaf 0.84 W/mK at 5% v/v moist
Inner leaf 0.62 W/mK at 1% v/v moist</td><td rowspan="2">EXISTING CONSTRUCTION</td><td>1. 2 x 103mm brick leaves, 50mm air cavity unplastered and uninsulated</td><td>0.84 External leaf brick 0.62 Internal leaf brick</td><td>256 Brick leaves and cavity</td><td>1.54</td></tr>
<tr><td>2. 2 x 103mm brick leaves, 50mm air cavity, with 13mm lightweight plaster on internal surface</td><td>0.16 Lightweight plaster</td><td>13 Lightweight plaster</td><td>1.37</td></tr>
<tr><td></td><td>3. As 1, with 13mm foil-backed plasterboard and expanded polystyrene composite on 20mm (min) battens to internal surface</td><td>0.037 Expanded polystyrene</td><td>60 Polystyrene + 33 Board & battens</td><td>0.43</td></tr>
<tr><td></td><td>4. As 1, with 9.5mm foil-backed plasterboard and 75mm rock fibre* to internal surface - 50mm spacer battens</td><td>0.04 Rock fibre</td><td>84.5 Board and mineral fibre</td><td>0.39</td></tr>
<tr><td></td><td>5. As 2, with cavity filled with blown rock fibre and 13mm lightweight plaster on internal surface</td><td>0.04 Specified cavity fill</td><td>13 Lightweight plaster 50 Specified cavity fill</td><td>0.56</td></tr>
</table>

* This term covers both glass and rock fibre.

10. Sources of further information

- ***EEO Publications:***

Copies of EEO publications and other literature applicable to energy efficiency in buildings are available from:

Enquiries Bureau
BRECSU (Building Research Energy Conservation Support Unit)
Building Research Establishment
Garston
Watford
WD2 7JR
Tel No: 01923 664258 Fax No: 01923 664787

Copies of EEO publications and other literature applicable to energy efficiency in industry are available from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Oxon
OX11 0RA
Tel No: 01235 436747 Fax No: 01235 432923

Information is also available through Regional Energy Efficiency Offices (REEOs).

- ***Organisations offering advice***

Building Research Establishment (BRE)
Garston
Watford
WD2 7JR
Tel No: 01923 894040

The Chartered Institution of Building Services Engineers (CIBSE)
Delta House
222 Balham High Road
London
SW12 9BS
Tel No: 0181 675 5211

- ***Insulation Suppliers:***

Names and address of manufacturers of suitable thermal insulation materials can be obtained from the following trade body:

Thermal Insulation Manufacturers and Suppliers Association (TIMSA)
PO Box 111
Aldershot
Hampshire GU11 1YW
Tel No: 01252 336318

- ***Insulation Contractors:***

A list of insulation contractors can be obtained from:

The National Federation of Roofing Contractors
24 Weymouth Street
London
W1N 3FA
Tel No: 0171 436 0387

Thermal Insulation Contractors Association
Kensway House
388 High Road
Ilford
Essex
IG1 1TL
Tel No: 0181 514 2120

- ***General Reference Material:***

BRE Digest 110: Condensation (HMSO)

BRE Digest 180: Condensation in roofs (HMSO)

BRE Digest 218: Cavity barriers and ventilation in flat and low pitched roofs (HMSO)

The Chartered Institution of Building Services Engineers, CIBSE Guides 1986: Books A, B and C

BRE Digest 108: Standard 'U' Values

- ***The latest news in energy efficiency technology***

'Energy Management' is a free journal issued on behalf of the EEO which contains information on the latest developments in energy efficiency, and details of forthcoming events designed to promote their implementation. It also contains information addresses and contacts for the REEOs.

Copies of 'Energy Management' can be obtained through:

Energy Management Journal
Emap Maclaren House
18 Scarbrook Rd
Croydon
Surrey
CR9 1QH

Appendix 1

Basic formulae for nomograms and the heat loss graph

A1.1 Nomogram 1

$$\text{Cost of heat (£/gross GJ)} = \frac{\text{Cost of fuel (£/unit of fuel)}}{\text{Calorific value (GJ/unit of fuel)}}$$

A1.2 Nomogram 2

$$\text{Cost of useful heat (£/UGJ)} = \frac{\text{Cost of heat (£/gross GJ)}}{\text{Boiler or appliance efficiency (\%)}} \times 100$$

A1.3 Nomogram 3

$$\text{Cost factor (£/W)} = \frac{\text{Cost of useful heat (£/UGJ)} \times \text{Evaluation period (hours)} \times 3.6}{10^6}$$

A1.4 Heat loss graph

$$\text{Heat loss (W/m}^2\text{)} = \text{‘U’ Value (W/m}^2\text{K)} \times \text{Temperature difference (K)}$$

A1.5 Nomogram 4

$$\text{Total cost of heat lost (£/m}^2\text{)} = \text{Heat loss (W/m}^2\text{)} \times \text{Cost factor (£/W)}$$

Appendix 2

Glossary

Hours of operation:

The operation period will vary with particular circumstances, giving many permutations of hours, days and weeks. As a guide, however, the following can be taken as being fairly representative for industry:

- 5,500 hours a year for continuous heating: 2 or 3 shifts, 7-day week;
- 2,000 hours a year for intermittent heating: 1 shift with some overtime, 5-day week.

K and °C:

Temperature difference in insulation calculations is expressed in Kelvin (K). A temperature difference of 1°C is equal to a difference of 1K.

Thermal conductivity - 'λ' value:

Thermal conductivity is a measure of the ability of a material to conduct heat. It indicates the rate of heat flow through a material and is expressed in units of W/mK (watt/metre Kelvin). The lower the 'λ' value, the better the insulation at preventing heat loss.

Note: The symbol 'λ' has been adopted for thermal conductivity in place of k, in accordance with current international practice.

'λ' values can be found in the CIBSE Guides 1986, Book A Section A3, BRE Digest 108 or from the insulation manufacturers.

Thermal resistance - R value:

The thermal resistance of a unit area of homogenous material can be found by dividing its thickness by its thermal conductivity, 'λ', i.e.:

$$R = \frac{L}{\lambda}$$

where:
- R = thermal resistance (m^2K/W)
- L = thickness (m)
- λ = thermal conductivity (W/mK)

R values are sometimes used by manufacturers or suppliers to denote the amount of insulation provided by a particular product; the higher the R value, the higher the insulation.

Example:

For a mineral fibre mat with a 'λ' value of 0.040W/mK, R values for 60 mm, 80 mm and 100 mm thicknesses would be as follows:

$$60\text{ mm } R = \frac{0.060}{0.040} = 1.5\ m^2K/W$$

$$80\text{ mm } R = \frac{0.080}{0.040} = 2.0\ m^2K/W$$

$$100\text{ mm } R = \frac{0.100}{0.040} = 2.5\ m^2K/W$$

It will be seen that, as opposed to 'λ' values, R values increase with higher insulation.

Thermal transmittance - 'U' value:

Thermal transmittance is the rate of heat flow in watts through a building element for each degree temperature difference between the ambient air on each side. It is expressed as W/m^2K and, as with 'λ' value, the lower the figure the better the thermal performance.

The 'U' value is a convenient way of enabling evaluation of heat loss, but is not something which is measured itself. 'U' values can be obtained either from manufacturers and suppliers or by using technical data.

The thermal transmittance of a building element can be found by adding the thermal resistances of component parts and taking the reciprocal. The 'λ' value or thermal conductivity of materials can be used to find the R value or thermal resistance of each component part.

As well as the 'R' values of the homogenous component parts, the resistance of any air space (R_a) and the internal and external surface resistances (R_{si} and R_{so}) must also be taken into account. The values of R_a, R_{si} and R_{so} vary according to circumstances. For example, the outside surface resistance (R_{so}) for roofs can be significantly affected by exposure, and in the case of walls orientation must be taken into account.

The 'U' value of a building element can therefore be defined as:

$$U = \frac{1}{R_{si} + R_1 + R_2 + \ldots + R_n + R_a + R_{so}}$$

where:

U	=	thermal transmittance (W/m^2K)
Rsi	=	inside surface resistance (m^2K/W)
$R_1, R_2 \ldots R_n$	=	thermal resistance of homogeneous components (m^2K/W)
R_a	=	air space resistance (m^2K/W)
R_{so}	=	outside surface resistance (m^2K/W)

Total R values (which include internal and external surface resistances) are sometimes given for insulation used in conjunction with certain structural forms. These can be regarded numerically as the reciprocal of the 'U' value ($\frac{1}{U}$).

If the existing 'U' value is known, it is possible to find the effect of changing one component for which the R value is known, as follows:

$$U_{existing} = \frac{1}{\text{Total of all existing resistances (R values)}}$$

If a component is added, the new 'U' value will be:

$$U_{new} = \frac{1}{\text{Total of all existing resistances (R values) + added resistance (R value)}}$$

or

$$\frac{1}{U_{new}} = \text{Total of all existing resistances + added resistance (R value)}$$

and

$$\frac{1}{U_{new}} = \frac{1}{U_{existing}} + \text{added resistance (R value)}$$

Example

The 'U' value of a roof with 80 mm thick insulation (rock fibre supported by 9.5 mm industrial grade plasterboard) is 0.42 W/m²K. If the insulation thickness is increased to 100 mm what will the new 'U' value be?

From Table 4, Section 9, the 'λ' value of the 80 mm insulant is 0.40 W/mK.

The additional thickness is 20 mm (100 - 80), i.e. 0.020 m.

Therefore, the added resistance,

$$R_{added} = \frac{L}{\lambda} = \frac{0.020}{0.04} = 0.5 \ m^2K/W$$

$$\frac{1}{U_{new}} = \frac{1}{U_{existing}} + \text{added resistance (R value)}$$

$$= \frac{1}{0.42} + 0.5 = 2.38 + 0.5 = 2.88$$

Therefore:

$$U_{new} = \frac{1}{2.88} = 0.35 \ W/m^2K$$

Appendix 3

Energy conversion factors

A3.1 Calorific values of fuel used for Nomogram 1

Type of Fuel		Heat value of energy inputs	Megajoules supplied
Coal [(1)]		265 therms/ton	27,500/tonne
Fuel oil[(2)]	Heavy	416 therms/ton (1.77 therms/gal)	43,200/tonne
	Medium	420 therms/ton (1.77 therms/gal)	43,600/tonne (186/gal or 41/litre)
Gas oil		438 therms/ton (1.64 therms/gal)	45,480/tonne (173/gal or 38/litre)
Gas		1 therm	105.5/therm

(1) The conversion factor is affected by the quality of the coal, particularly the moisture and ash content. This value is typical for industrial coal.

(2) Figures are given for the most common grades of heating oils - your fuel supplier can provide details for the particular oil you buy

A3.2 Conversion factors for units used in this booklet

	Units used	Conversion factor	Imperial Units
Temperature	°C	x 1.8 + 32	°F
Length	mm m	x 0.0394 x 3.2808	in ft
Volume	litres	x 0.2200	gal
Weight	tonne	x 0.9842	Ton
Energy	GJ	x 9.4782 x 0.2778	therm kWh
Heat flow rate	W/linear m	x 1.0400	Btu/ft h
Thermal conductivity	W/mK	x 6.9335	Btu in/ft^2h°F
Thermal transmittance	W/m^2K	x 0.176	Btu/ft^2h°F
Thermal resistance	m^2K/W	x 5.678	°F/Btu in

For fuel oil the number of litres in a tonne = 1,047 assuming an average density of 955 kg/m^3
For gas oil the number of litres in a tonne = 1,195 assuming an average density of 837 kg/m^3

Other conversion factors can be found in the CIBSE Guides 1986, Book C Section C7.

Titles in the Fuel Efficiency Booklet series are:

1 Energy audits for industry
1 Energy audits for buildings
2 Steam
3 Economic use of fired space heaters for industry and commerce
4 Compressed air and energy use
7 Degree days
8 The economic thickness of insulation for hot pipes
9 Economic use of electricity in industry
9 Economic use of electricity in buildings
10 Controls and energy savings
11 The economic use of refrigeration plant
12 Energy management and good lighting practices
13 Waste avoidance methods
14 Economic use of oil-fired boiler plant
15 Economic use of gas-fired boiler plant
16 The economic thickness of insulation for existing industrial buildings
17 Economic use of coal-fired boiler plant
19 Process plant insulation and efficiency
20 Energy efficiency in road transport

Fuel Efficiency booklets are part of the Best Practice programme, an initiative aimed at advancing and promoting ways of improving the efficiency with which energy is used in the UK.

For copies of Fuel Efficiency booklets or further information on industrial projects, please contact:

Energy Efficiency Enquiries Bureau
ETSU (Energy Technology Support Unit)
Harwell
Oxon OX11 0RA
Tel No: 01235 436747 Fax No: 01235 432923

For copies of Fuel Efficiency booklets or further information on buildings-related projects, please contact:

Enquiries Bureau
BRECSU (Building research Energy Conservation Support Unit)
Building Research Establishment
Garston
Watford WD2 7JR
Tel No: 01923 664258 Fax No: 01923 664787

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